

## N O T I C E

THIS DOCUMENT HAS BEEN REPRODUCED FROM  
MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT  
CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED  
IN THE INTEREST OF MAKING AVAILABLE AS MUCH  
INFORMATION AS POSSIBLE

Report No.  
DOE/JPL 955846-81/1

Report of an  
Exploratory Study:

SAFETY AND LIABILITY CONSIDERATIONS  
For  
PHOTOVOLTAIC MODULES/PANELS

(NASA-CR-103942) REPORT OF AN EXPLORATORY  
STUDY: SAFETY AND LIABILITY CONSIDERATIONS  
FOR PHOTOVOLTAIC MODULES/PANELS  
(Carnegie-Mellon Univ.) 57 p HC A04/MF A01

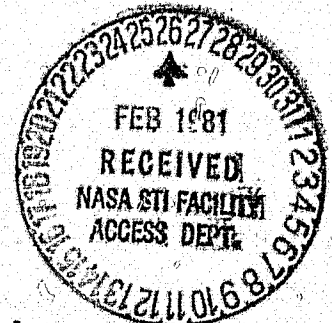
N81-17524

Unclass  
CSCL 10A G3/44 41370

LOW COST SOLAR ARRAY PROJECT

January 1981

Prepared For  
Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California 91103



Prepared By  
Mechanical Engineering and Public Policy  
Carnegie-Mellon University  
Pittsburgh, Pennsylvania 15213

Report No.  
DOE/JPL 955846-81/1

REPORT OF AN  
EXPLORATORY STUDY:

SAFETY AND LIABILITY CONSIDERATIONS  
FOR  
PHOTOVOLTAIC MODULES/PANELS

LOW COST SOLAR ARRAY PROJECT  
January, 1981

Prepared For  
Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California 91103

Prepared By  
A. S. Weinstein  
D. G. Meeker  
Mechanical Engineering and Public Policy  
Carnegie-Mellon University  
Pittsburgh, Pennsylvania 15213

## ACKNOWLEDGEMENT

The assistance of Mr. E. Royal of the Jet Propulsion Laboratory is gratefully acknowledged.

## TABLE OF CONTENTS

	<u>Page</u>
DISCLAIMER. . . . .	1
INTRODUCTION. . . . .	2
APPROACH. . . . .	3
ELEMENTS OF SAFETY DESIGN REVIEW PROCEDURE. . . . .	4
DOCUMENTATION . . . . .	6
A DESIGN REVIEW BOARD . . . . .	8
ILLUSTRATIVE HAZARD ASSESSMENT FOR PHOTOVOLTAIC MODULE/ARRAYS . .	9
MANUFACTURING AND ASSEMBLY. . . . .	10
SHIPPING AND HANDLING . . . . .	11
INSTALLATION. . . . .	14
OPERATION AND MAINTENANCE . . . . .	19
NATURAL EVENTS. . . . .	22
OTHER EVENTS. . . . .	23
FMEA/FTA. . . . .	25
FMEA. . . . .	27
FTA . . . . .	33
SUMMARY . . . . .	43
APPENDIX A. . . . .	44
APPENDIX B. . . . .	46
APPENDIX C. . . . .	50
BIBLIOGRAPHY. . . . .	52

## DISCLAIMER

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees make any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

## INTRODUCTION

The concept of product liability implies that a manufacturer is responsible to the consumer for products that are not reasonably safe. Recently, consumers have become more and more aware that manufacturers could be liable for harm incurred by a consumer while using their products.<sup>1</sup> Evidence of this awareness can be seen by the increase in product liability suits and sizes of awards in recent years. Clearly this presents a problem for the manufacturer. Not only must the product be reliable and safe for its intended purpose, but it must also be safe for foreseeable misuse.

This preliminary report explores product safety and product liability considerations for photovoltaic module/array devices. The purpose of this study is twofold--first to give an overview of legal issues as they apply to design, manufacture and use; second, to suggest a methodology to be used during design of a photovoltaic module/array to minimize or eliminate perceived hazards. This study does not attempt to answer any of these questions in detail, but only to pose them so as to stimulate consideration of this area. The questions raised in this study can only be answered through future efforts in concert with the manufacturers.

---

<sup>1</sup>1916 Macpherson vs. Buick Motor, Inc. The courts rules that there no longer had to be a direct contractual relationship between buyer and manufacturer in order for the buyer to recover from harm incurred using a defective product.

1945 Escola vs. Coca Cola. This decision extended the legal basis of recovery to include strict liability in cases involving construction defects.

1963 Greenman vs. Yuba Power Products, Inc. The court extended strict liability to include design defect cases.

## APPROACH

In order to supplement the basic study, certain additional activities were pursued. First, a general review of photovoltaic literature was made using computerized literature searches. Data bases included D.O.E. energy file, NTIS file, Compendex file, Conference Paper Index and others. A literature search was also made of relevant legal material as it applies to design.

Examination was made of four block III photovoltaic panels. The panels included the shingle type as well as panel type collector.

Plant trips were made to a number of photovoltaic manufacturers. These trips not only included plant tours of manufacturing, testing and shipping facilities but also included discussion on design and safety aspects of photovoltaic modules. Manufacturers visited included Solar Power Corporation, Solarex Corporation, and General Electric Company.



## ELEMENTS OF SAFETY DESIGN REVIEW PROCEDURE

Fundamental to the concept of weaving safety considerations into the design of a product is to recognize that there are three elements which interact to create hazards with a consequent risk of injury: the product, the person and the environment within which they function. It is thus essential to outline a structured method which permits the designer to address these elements in a rational way.

The steps listed below are an outline of a safety design review procedure.\*

1. Delineate the scope of product uses.
2. Identify the environments within which the product will be used.
3. Describe the user population.
4. Postulate all possible hazards including estimates of probability of occurrence and seriousness of resulting harm.
5. Delineate alternative design features or production techniques including warnings and instructions, that can be expected to effectively mitigate or eliminate the hazards.
6. Evaluate such alternatives relative to the expected performance standards of the product, including the following:
  - a) other hazards that may be introduced by the alternatives
  - b) their effect on the subsequent usefulness of the product
  - c) their effect on the ultimate cost of the product
  - d) a comparison to similar products
7. Decide which features to include in the final design.

The safety design procedure listed above should begin after the initial design has been formulated. The process begins by identifying the actual scope of the product uses, where the product can be expected to be used, and who will be using it. It is critical at this stage that foreseeable misuses be thoroughly explored together with the

---

\*See, Products Liability and the Reasonably Safe Product, A. S. Weinstein, et al., John Wiley & Sons, New York.

actual limitations and responses of the users. Taken together, they set the boundaries of foreseeable use and misuse and foreseeable users. Users will inevitably have a broad range of manual dexterity, strength, and levels of understanding and awareness. Once the product use and user situations are postulated, the next task is to identify the hazards that are likely to arise from the interaction of the product use, environment, and user. This is done, principally, by postulating scenarios of occurrences which can lead to hazards.

The hazards having been identified and the probability and gravity of the harm that might result having been estimated, the question becomes, what changes, in design, can minimize or eliminate the risk of injury? It is at this point that the problem of design changes versus warnings to minimize a given risk must be carefully assessed. For each warning or design change some estimate should be made of the reduction in both probability and gravity of harm, since such reduction can have a significant impact on the ultimate production cost. Caution must be exercised when suggesting design changes because the new design may substitute a new hazard for the one(s) being eliminated.

It is also possible to take a safe product and make it unsafe by creating unrealistic expectations in the mind of the user through expressed or implied warranties. Recent court interpretations have included advertisements and sales literature in decisions about warranties and have concluded that where advertising leads a user to false expectations of the product, the manufacturer is liable for damages, despite disclaimers in other literature.

As each consideration is addressed, the effects on product usefulness and cost must obviously be introduced. But product cost is not based solely on materials, labor, marketing, overhead, and profit. Part of the product cost is that arising from possible injuries, either from the expected fraction of products marketed with production flaws or from hazards that the design did not minimize. Whether these costs are, in part, insurance premiums, settlements, judgments, or legal fees is not important. They are part of the real cost of the product and can significantly affect decisions about which safety features to incorporate in the final design. Certainly, some of these costs (e.g., settlement, judgments) are not factors for a court in deciding whether a product is unreasonably dangerous. A court performing a risk-utility analysis could not account for a manufacturer's settlement practice. Nonetheless, these considerations may weigh heavily on the manufacturer when it decides on its design or quality control standards.

## DOCUMENTATION

The methodology described in the preceding section is critical for establishing how and why the complex trade-offs were made in order to reach the final design, including all of the literature that communicates to shippers, installers, users as well as to repair and maintenance personnel. If all of this effort is not clearly and comprehensively documented an important dimension of the process will be lost. The manufacturer must be able to assess the efficacy of his decision-making process, once field data becomes available. In addition, if the manufacturer is alleged to have produced a defective product and is sued, it is crucial that he be able to rebut such arguments by demonstrating the care used in designing, manufacturing and marketing the product. For these reasons it is essential that the manufacturer keep a comprehensive record of the process that elucidates all of the considerations upon which the design is based.

Such documentation can be categorized as:

1. Hazard and risk data--historical, field, and/or laboratory testing, causation analyses.\*
2. Design safety formulation--fault tree, failure modes, hazard analyses.
3. Warnings and instruction formulation--methodology for development and selection.\*\*
4. Standards--the use of in-house, voluntary, and mandated design or performance requirements.
5. Quality assurance program--methodology for procedure selection and production records.
6. Product performance--reporting procedures, complaint file, follow-up data acquisition and analysis, recall, retrofit, instruction and warning modification.
7. Decision making--the "how," "who," and "why" of the process.

These are the necessary elements for the data base supporting the product safety design review. A comprehensive exposition of the basic data, coupled with the sensitivity of the decision-making process as

---

\*Appendix B contains sample of field data.

\*\*Appendix A contains guidelines for warning development.

illustrated through significant documentation, can provide the courts, as well as the manufacturer, with the benchmarks needed for judging a product's societal acceptability.

The hazard and risk data not only should be acquired from well-designed laboratory and field tests but also should include analyses of any litigation, user complaints, and field failures. Finally, careful scrutiny of both a given manufacturer's liability claims and reported appellate decisions for all products of the same type throughout the country can uncover problems or use patterns that are important for retrofit considerations as well as for design review.

## A DESIGN REVIEW BOARD

The implementation of a product safety design review requires contributions from a variety of disciplines, as well as differing viewpoints within a given discipline. Judging the boundaries of human behavior and product behavior is too complex to be left in the hands of one person or discipline.

The tasks of a design review board are to elicit and evaluate data and to articulate the competing elements for the decision-making process, not to redesign the product. Included in the responsibilities of the group should be a review of all packaging, labeling, instructions, and advertising material, since the explicit representations are an essential dimension of the expected performance of a product.

The group performing the product design review should be composed of members from the manufacturer's organization as well as ancillary skills from the outside:

1. Engineering or design
2. Production
3. Quality assurance
4. Testing
5. Service
6. Marketing
7. Psychology and human factors
8. Legal

Corporate management should designate a person whose sole responsibility is product safety assurance to chair the design review board. There must be established a decision-making process and a review mechanism for critical decisions which include participation by senior corporate members.

Perhaps the most important tasks to be undertaken by this board, collectively, are the identification of the product uses and misuses, the nature of the users and the actual product environment. Based upon these elements, the board must then construct the hazard scenarios and postulate the relative degree of seriousness posed by them. Once design modifications, including warnings and instructions, have been postulated, perhaps by the engineering department, the board must then assess the proposed changes and make recommendations concerning the design formulation that is to be adopted.

## ILLUSTRATIVE HAZARD ASSESSMENT FOR PHOTOVOLTAIC MODULE/ARRAY

The preceding sections described, in general terms, the nature of the design safety review process. In this section, an illustrative analysis is presented to demonstrate how this process is to be applied to photovoltaic module/arrays. The analysis is not complete, nor is it intended to offer solutions to the myriad of problems faced in the design process. Its principal goal is to stimulate an awareness of the nature of the problems as well as suggested methods for seeking solutions. Ultimately, it is only through group effort, rational approach and honest assessment that what is initiated here can be completed.

There are six areas to be considered individually for which a hazard assessment should be undertaken:

1. manufacturing and assembly
2. shipping and handling
3. installation
4. operation and maintenance
5. natural events
6. other events

In each of the above areas a scenario of an accident will be developed as an example of the type of thought process involved. This will be followed by a table suggesting other scenarios and a ranking of probability of harm P and the seriousness of the resulting harm S.

The probability of harm multiplied by the seriousness of harm ( $P \times S$ ) permits a relative ranking of the listed hazards. A numerical scale of values from one to ten will be used for both the probability and seriousness scales. A seriousness of ten represents critical injury or death, while a probability of ten would indicate that the hazard will occur every time a person comes in contact with or uses the product.

Following this ranking, suggested recommendations are listed which are intended to eliminate or reduce the probability of harm and the resulting injury.

It should be noted that the numerical values listed for the probability of harm (P) and the seriousness (S) are, for the most part, subjective assessments since little, if any, data are available. The numbers are not to be viewed as absolute in any sense, but are used to assess the relative rankings of hazard as a guide to the design formulation. It is one of the functions of the design review board to develop these rankings, collectively, based upon whatever data and perceptions that can be brought to bear on the problem. Much of the time, however, the hazard index will be based upon subjective analysis, rather than objective data. The integrity of the process thus rests on a thoughtful, careful and complete analysis.

## MANUFACTURING AND ASSEMBLY

As the terrestrial photovoltaics market begins to grow, production techniques for automated cell fabrication and assembly will begin to appear. Until the large volume terrestrial photovoltaics module market develops, many companies will be using hand assembly lines. Evaluation of worker safety in a manufacturing environment is a well known and documented subject. Many insurance companies have a review program for their clients. The Occupational Health and Safety Administration has regulations and guidelines on worker safety. One area that needs further investigation is the effects of exposure to silicon either directly or indirectly. The major source of silicon exposure is in the cutting of silicon to make cells which is currently controlled by exhaust loads. Exposure to solvents from encapsulant materials may also be a problem. Although not a hazard in the area of manufacture and assembly, problems arising from quality assurance can emerge later in the operation of array system. For example, poorly soldered connections can lead to hot spots which could lead to system degradation and/or a possible fire.

Endemic Hazard	Probability P	Seriousness S	P x S
1) Exposure to Toxic Materials	8	3	24

### Recommendations

1. The general hazards associated with the workplace are to be addressed using OSHA regulations.
2. Obtain data on toxicity problems associated with silicon and solvents and utilize whatever assistance the National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) can give in instituting procedures to minimize or eliminate potential hazards in these areas.

## SHIPPING AND HANDLING

Shipping and handling represent an area in which the manufacturer must take precaution to decrease hazards related to his product. Modules can range in size from 48" x 48" to 32" x 96" and can weigh anywhere from 70 to 240 pounds, depending on the material and size. It is obvious that panels will often travel great distances by several means of transportation and be handled several times in their transit. Thus a possible accident is the dropping of the photovoltaic panel container. This dropping could result in a minor injury to the person carrying the container. If the container is then opened and if the glass cover plate is broken or shattered, injury could result from the broken glass. If the container is opened and exposed to light, when examining the module for damage, a person could be startled and suffer injury by falling or in other foreseeable ways, if the terminals are shorted and a minor, non-lethal shock occurs.

Since panels can be and are sold individually, off-the-shelf, an unskilled user would not necessarily be aware of the electrical hazard which would result from daisy-chaining. Alternatively, series-wired panels capable of producing up to 600 volts each, could pose a serious hazard individually or inadvertently miswired in an array. The high probability of such events suggests that each and every panel should contain an appropriate, permanent warning.

Scenario	Probability* of Harm	Probability of Seriousness	P x S
1) electrical shock from module (series wired)	7	6	42
2) electrical shock from sub-array (pre-wired)	6	8	48
3) injury due to broken glass	5	5	25
4) localized burns from electrical shock	7	7	49
5) reverse bias leading to fire	1	2	2
6) injuries resulting from dropping of containers	3	5	15



7) other injuries from  
minor shock

2

5

10

\*These are the estimated probabilities of injury occurring once an event, such as dropping a container, has occurred. No estimate is given here as to the probability of the event occurring in the first place. The event probability must be estimated in order to rank all hazards from all sources.

From these hypotheses and their relative ranking, a sense of the magnitude of the problems is generated. If it is concluded that these problems warrant attention, then consideration as to possible solutions is to be developed. For example, glass breakage could be reduced by using thicker glass. But this change will increase panel weight, lower efficiency, increase cost and can increase the severity of the injuries resulting from the dropping of a panel or container.

Alternatively, each panel could be covered with opaque, adhesive paper. This would minimize injuries from glass breakage and keep the panel electrically inactive under most foreseeable circumstances until it is deliberately removed. If the glass breakage problem is not considered serious, but the electrical hazards are deemed important, then a shunt resistor could be installed on each panel and/or plastic guards placed over the output terminals that are difficult to remove or require a special tool for removal could be considered. Finally, it may be decided that only a warning be applied to each panel and no design change is necessary at all.

If modules are shipped in containers, their design should not be overlooked. In establishing a basis for the integrity of such a container, an appropriate drop height and surface should be decided. For example, is a design drop height of eight feet more appropriate than four feet, if shipping is likely to be by railroad?

Such decisions and the trade-offs involved must be made consciously and documented together with the reasoning supporting the final decisions.

To summarize, the alternatives described above, arising from the scenarios, are:

1. Install a shunt resistor in each panel.
2. Install plastic guards over the module's electrical output terminals.
3. Use thicker glass panel.
4. Cover the panel front with non-transparent paper.
5. Place warnings and/or instructions on each panel.

After alternatives have been described, some estimate as to their effectiveness should be postulated. Again, it is a subjective determination. However, this will permit assessing whether or not any reasonable reduction in hazard level could be achieved. Listed below is the estimated change in each risk of injury, if, for example, all of the alternatives in the list were incorporated.

Scenario	Probability of Harm	Probability of Seriousness	P x S
1) electrical shock from module	1	6	6
2) electrical shock from sub-array	1	8	8
3) injury due to broken glass	1	5	5
4) localized burns from electrical shock	1	7	7
5) reverse bias leading to fire	1	2	2
6) injuries resulting from dropping of container	3	2	15
7) other injuries from minor shock	1	2	2

Tables such as the preceding ones would then permit the formulation of benefit/cost analyses of the suggested alternatives, based in part upon the projected reduction in both probability and seriousness of harm. The design review group would then be in a position to make recommendations as to which, if any, design changes will meet all of the manufacturer's constraints as a reasonable balance of all considerations.

These analyses, coupled with all of the rationale supporting the decisions, become both the focus and the source of the product safety review as an integral part of the design, manufacture and marketing functions.

## INSTALLATION

The risks of injury in the installation of arrays are somewhat dependent on which type of panel is used--either the shingle type (Figure 1a and b) or the module type. For the module type there are four different mounting systems: rack mount, standoff mount, direct mount, and integral mount (Figure 2). Because the rack mount system is at ground level it is easier to install and maintain but at the same time has a higher hazard level because of its general accessibility in contrast to arrays mounted on the roof of a dwelling.

Scenario	Probability of Harm	Probability of Seriousness	P x S
1) injury during unpacking	3	5	15
2) electrical shock from array during installation	7	6	42
3) electrical shock from cabling	7	8	56
4) localized burns from electrical shock	7	7	49
5) injury to others, when job site is unattended	8	8	64

Some of the possible considerations which could eliminate or minimize the risks of injury:

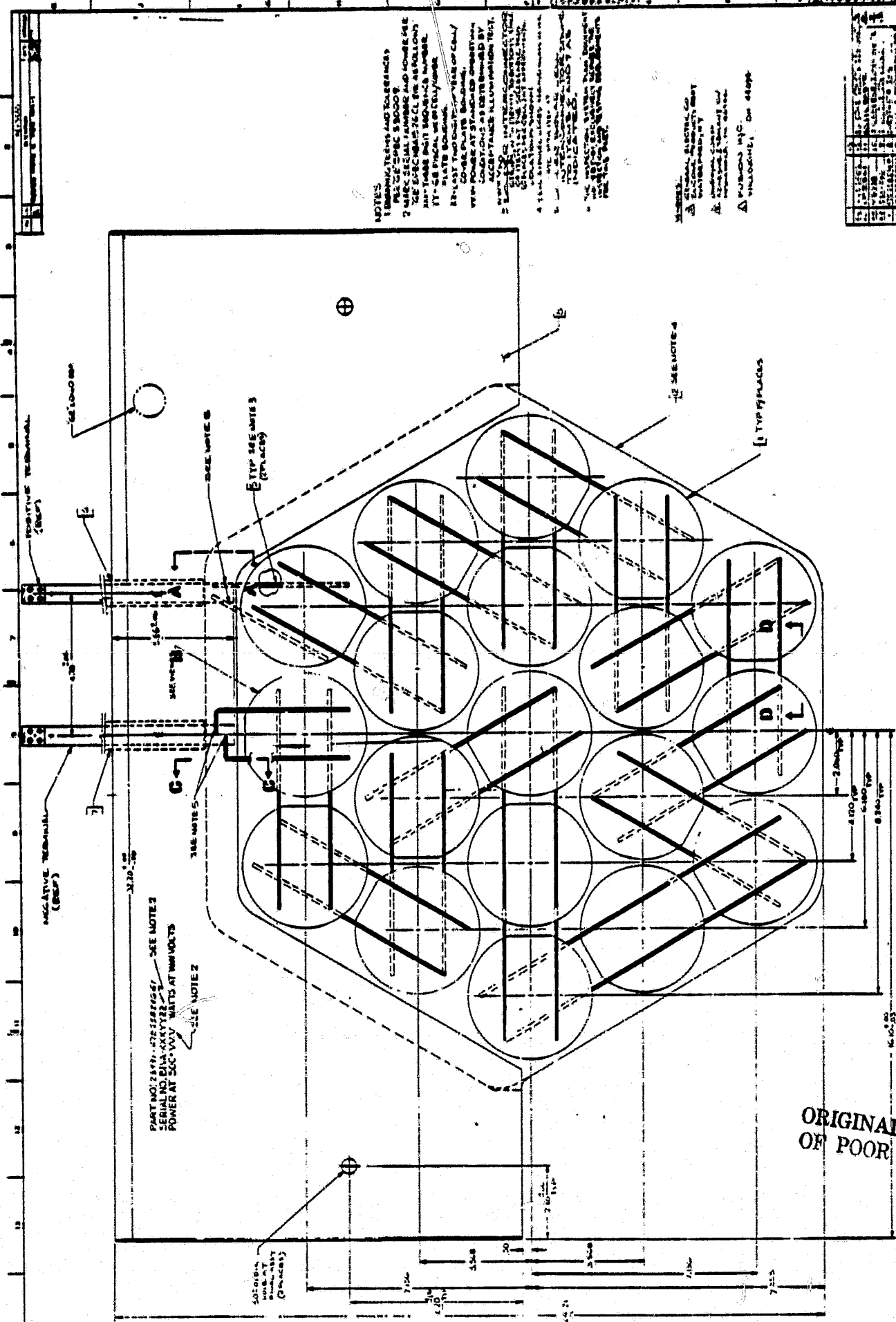
1. Every installation to have documentation to cover
  - a) unpacking of modules
  - b) site preparation and module storage
  - c) safe installation practices
  - d) procedures when job site is left unattended
  - e) start up, check out, shut down procedures\*

---

\*A sample of this type of documentation is given in Appendix C.

2. Cabling and connectors be protected against shock by guarded plugs, requiring special tools for removal.

This listing is not intended to be complete, but serves to point out that installation can create risks of injury to two distinct classes of persons: the installer and the curious bystander, adults as well as children, attracted by the novelty of the installation. The installer must be given adequate and easily understood instructions for the problems of installation. But the risks that can arise when the job site is left unattended each day and over weekends especially when the system is only partially completed presents hazards that may equal or exceed those to which the installer is exposed. In the current legal climate, the manufacturer is expected to and is held to foreseeing such highly likely events as well as anticipating inadequate job-site practices by installers.



ORIGINAL PAGE IS  
OF POOR QUALITY

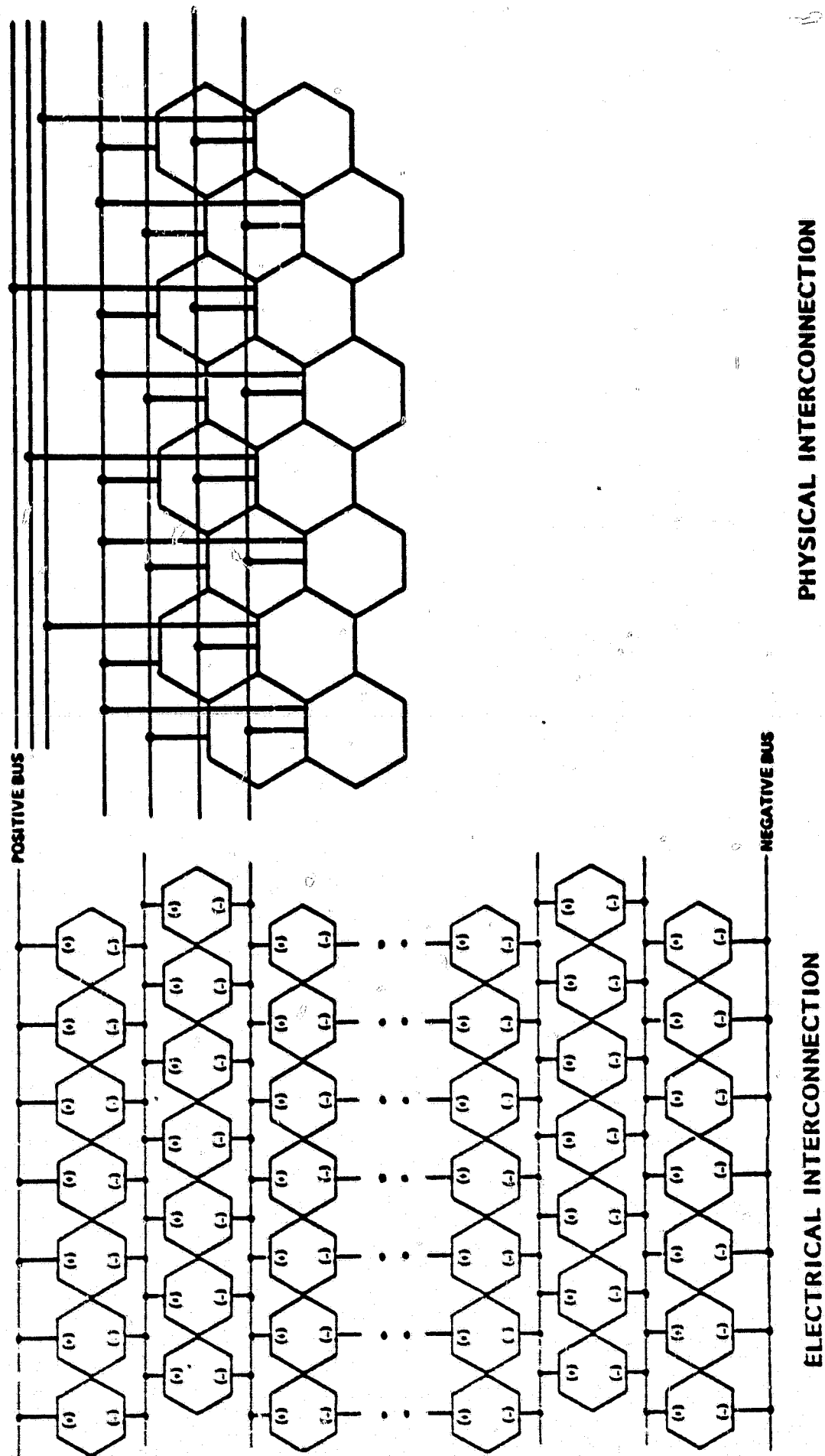
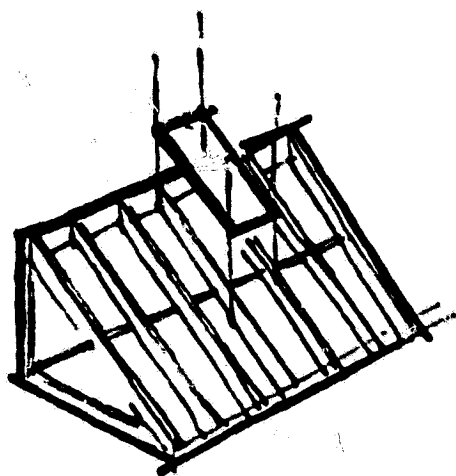
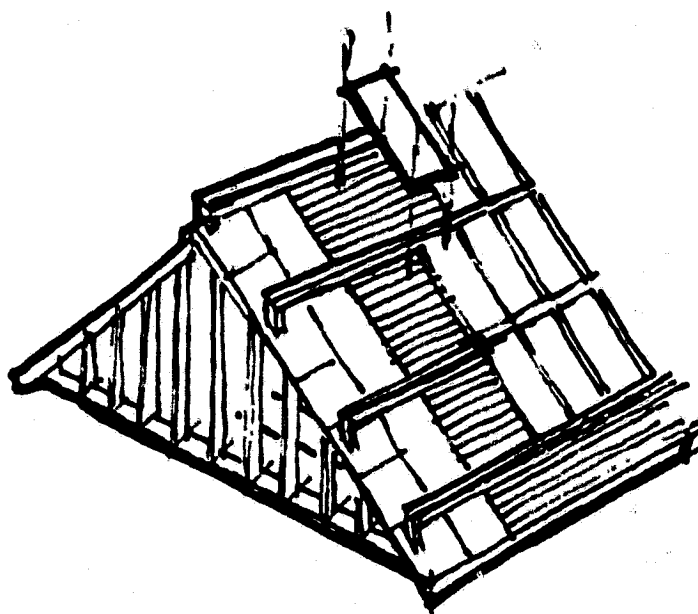


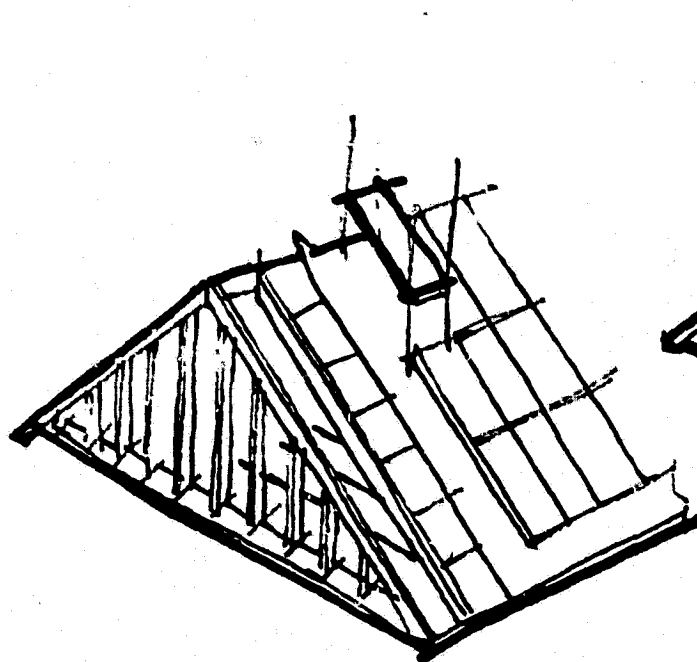
Figure 1b



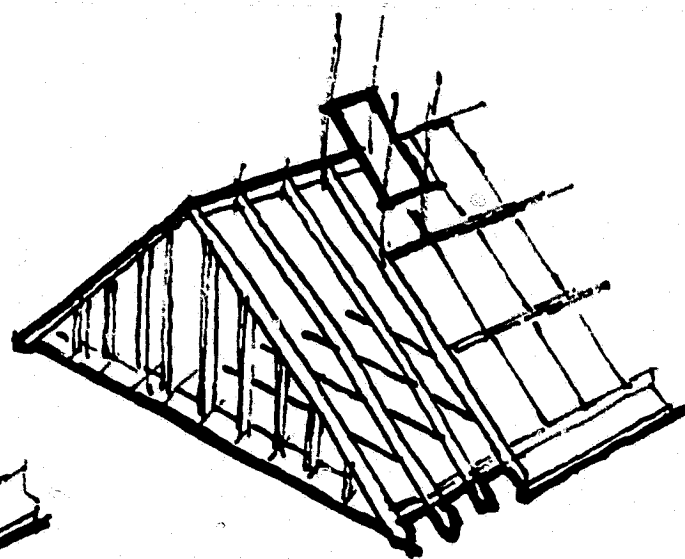
Rack



Standoff



Direct



Integral

Figure 2

## OPERATION AND MAINTENANCE

It is in the area of residential operation and maintenance that many accidents will arise from unskilled persons interacting with the photovoltaic system. The number of times that the following events will occur will largely depend on the type of installation and its geographical location. The activities that will precipitate the events are general maintenance, panel cleaning, panel replacement, wiring repair, and gasket repair.

Scenario	Probability of Harm	Probability of Seriousness	P x S
1) walks on array breaks glass	3	5	15
2) slides off array and falls	6	7	42
3) electrically shocked from array	4	8	32

Some of the possible considerations that could eliminate or minimize the risks of injury:

1. Documentation in the form of a detailed step-by-step outline procedure be supplied on all aspects of the photovoltaic array system.
2. An access system such as the one depicted in Figure 3.
3. A control panel to read I-V curves for each string.
4. Need for special tools, that are unavailable to a user, in order to undertake electrical repairs.

Apart from the considerations listed above, a broader view of the problem could consider (a) including a service contract in the price of an installation, with repairs and maintenance to be performed only by authorized persons; (b) limiting or controlling sales of panels only to such authorized maintenance and repair groups, making them inaccessible to unskilled persons.

It is evident that the problems envisioned here begin with the unskilled home-owner using an aluminum ladder to climb to the roof in order to discover the source of a problem. It is this foreseeable eventuality, with a high probability of risk, that a manufacturer



should consider in the entire spectrum of uses of his product. It is clear, today, that a manufacturer of panels will not be able to defend liability simply by stating that he was not responsible for the entire system, if in fact, he holds himself knowledgeable for any system design.

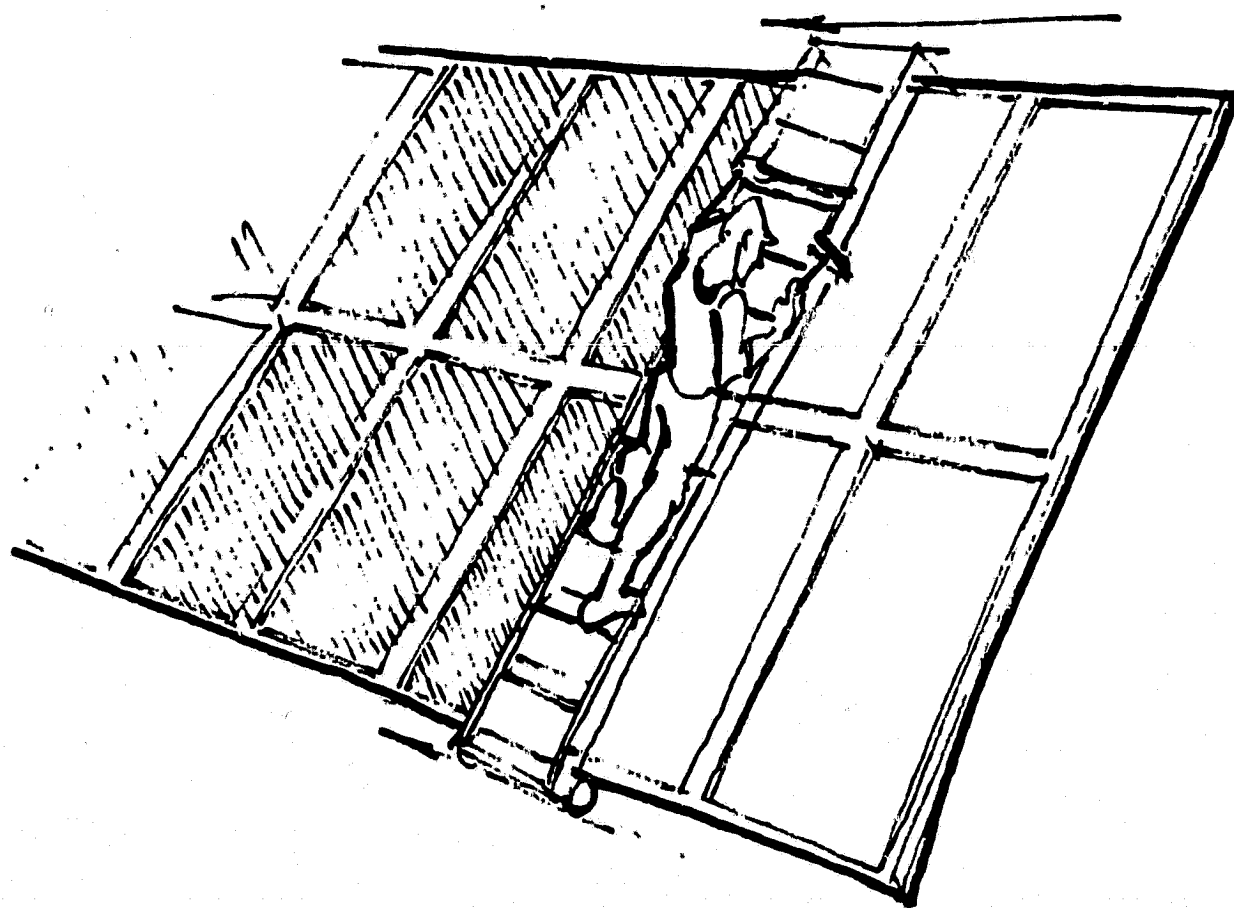


Figure 3

## NATURAL EVENTS

There are many scenarios that can be proscribed around what are termed "natural" events. Only a few are postulated here in order to illustrate the nature of the concerns that should be addressed.

### Fire

An array in a residential or commercial setting could be exposed to fire caused by conditions unrelated to the panels. Are there any special problems that can arise when an array is exposed either to direct fire or to intense heat and then sprayed with water? Have any tests been conducted to discover the effect of such exposure? When a fire occurs in daylight, what strategies are appropriate for informing fire fighters and others of a concurrent danger of electrical shock when in close proximity to the array?

### Snow

When snow accumulates on a roof array and sufficient sunlight penetrates to warm up the panel by its operation, a condition exists for the entire snow load to slide off. If the probability of this event is significantly greater than that for existing roofing materials, should some provision be incorporated in the system design to minimize the potential hazards to passersby or property in the vicinity?

### Lightning, Hail, Sandstorms, Corrosive Atmosphere

Each of these events and others could present concerns in the areas of use, performance and/or risk of injury. To what extent have these areas been addressed, tested for and design decisions articulated? The panels, the array, the structure and the wiring, viewed as a system, should be examined in the light of the effects of such natural events on each of the elements and then on the entire system.

It is clear that before any performance or design standards can be formulated, all likely events should be addressed, whatever data is available should be collected and analyzed and tests should be devised and conducted. Following this, reasonable standards can be postulated and developed to achieve a reasonable balance among safety, performance, useful life, repair and cost.

## OTHER EVENTS

### Attractive Nuisance

Apart from, and in addition to, the hazards described earlier for each of the principal areas from manufacturing to operation and maintenance, there exists the potential problems that could arise from the unfamiliarity and hence attractiveness of an installation. The youngsters who view the array as a target for BB guns or other weapons and who may be injured as a result are a potential for liability. In order to discover just what this array does, the curious will climb fences and roofs to satisfy that desire. Can additional precautions be taken in design to account for the inevitability of such events, recognizing that warnings alone are unlikely to suffice? Whether or not any design alterations can be or are formulated to account for such events, the decisions must ultimately be based upon careful, documented assessment.

### Auxiliary Electrical Systems

#### A. Storage Devices

In all probability, a large number of residential photovoltaic systems will utilize batteries for storing energy. While the maintenance and safety of DC battery storage systems is well known and documented, such information and appropriate precautions must be part of the concern of the module manufacturer who prescribes, gives consultation on or designs complete systems. The following areas should be addressed for a battery storage system: Electrical protection, chemical hazards, fire hazards and concerns for control, monitoring and ventilation.

#### B. Utility Backup

Another proposed auxiliary system is that of interconnection with a public utility. The obvious concerns arise from

- (a) the need for an automatic disconnect between the photovoltaic system and the utility's lines, if the utility suffers a complete loss of power.
- (b) The problem faced by a utility if a significant feed by a large number of photovoltaic arrays is suddenly lost because of a natural event or other cause.

In the former event, if there is not an automatic disconnect, a lineman may suffer injury if the array is feeding into what is believed to be a dead line. In the second event, the utility may not be able to pick up the load caused by a loss of the photovoltaic source rapidly enough to avoid either a blackout or a rapid drop in voltage. If significant damage occurs, there will inevitably arise the question of responsibility and hence liability.

These areas, too, should be given consideration, not only by module manufacturers who may have to share at least some of the responsibility, but the other viable entities including battery manufacturers and the public utilities.

## FMEA/FTA\*

The FMEA is a technique for systematically identifying, analyzing and documenting the possible failure modes within a design and the effects of such failures on system performance and personnel safety. The FMEA is a bottom-to-top analysis which begins at the bottom, the component level, and works upward to the end product or system level where the effect of the failure on system performance or personnel safety is determined.

The FTA is similar to the FMEA in that it too is a technique for systematically identifying, analyzing and documenting potential safety and reliability problems. The FTA differs from the FMEA in its method of documentation and in the fact that it is a top-to-bottom analysis. It begins with an assumed undesirable event at the top or system level and identifies the events at subsequent lower levels in the system that can cause the undesirable top event.

The purpose of both the FMEA and FTA is to identify areas in the design or hardware where improvements are required to ensure the system will be reliable and safe for its intended use and reasonably foreseeable misuse. The FMEA/FTA can serve to increase the efficiency and productivity of design reviews by focusing design review emphasis on weak areas in the design; it can also serve as a source of material for use in preparing reliability and quality assurance test programs, and in preparing care and use books or repair and maintenance manuals.

### Who Conducts the FMEA/FTA?

Generally, the FMEA or FTA can be performed more quickly by the responsible design engineer because he is most familiar with his design. Having a reliability engineer perform the analysis allows a fresh objective analysis of the design. If the analysis is conducted by the design engineer, it should be checked by the reliability engineer, and vice versa. Together they go over the possible failure modes, possible causes, how failures would be evidenced or detected, the consequences of failures both on the performance and safety of the product.

### When to Use FMEA/FTA?

The FMEA/FTA should become an integral part of the normal product design process.

The primary purpose of the FMEA/FTA is, as stated earlier, to identify areas in the design or hardware where improvements should be

---

\*Much of this information was extracted from the Westinghouse Electric Corporation booklet entitled: A Guideline for the FMEA/FTA. FMEA: Failure Modes and Effects Analysis; FTA: Fault Tree Analysis.

made to ensure the system will be reliable and safe for its intended use and reasonably foreseeable misuse. Positive action must be taken to correct the deficiencies highlighted by the FMEA or FTA before the job can be considered completed. Design changes can be made most effectively during the design stage. Making the necessary changes after the product is in production is more costly. No new product design or major redesign should be released for production without an FMEA or FTA having been conducted and the follow up actions accomplished.

Use the FMEA when primary emphasis is to be placed on assuring that each component in the design will be examined for possible failure modes and the effect on the overall design.

Use the FTA when primary emphasis is to be placed on analyzing specific undesirable top events for identifying causes and their probabilities of occurrence.

## FMEA

FMEA Procedure

The FMEA procedure described in this guideline is a basic procedure. There is no one right way to perform an FMEA or one right format to use. The important thing is that a form such as the one shown in Figure 4 be used to guide the analysis through a systematic process and document the results.

The FMEA, as described herein, is sometimes called a failure mode effects and criticality analysis (FME & CA) because the criticality of each failure mode is analyzed in this procedure.

*STEP 1--Collect the Data to be Used in the Analysis*

First, collect the information for conducting the FMEA including drawings, schematics, layouts, parts lists, bill of materials, information on the operating environment, and any other descriptive information on system operation which may be available. Other useful documents might be the product design specification and other specifications, industry or association standards, and perhaps particulars from the contractual requirements. If the system is in the early stages of its design and development, the information available for FMEA may be limited, and the depth of analysis will be limited. However, if the design is completed or a prototype hardware model exists, the analysis will result in a thorough examination of the system.

*STEP 2--Prepare a Form for the Analysis*

Figure 4 describes a sample form which can be used for the FMEA. There is no one correct form to use. Prepare a form which best suits the person conducting the analysis and the design or hardware being analyzed.

*STEP 3--Sequentially list each part to be analyzed by part number and by name**STEP 4--Briefly describe the function(s) of each part in the system**STEP 5--List the possible failure modes in which each part can fail*

Frequently there are two or more failure modes for a part, each of which could cause different effects on the system performance or personnel safety.



**STEP 6--List the effect each failure mode would have on system performance**

For each failure mode identified for a particular part, list the effect which that failure could have on the system performance. It is quite useful to describe the effect on system performance as it would be seen through the eyes of the user. For example, it would be better to explain "Dirt on panel surface" rather than "reduction of system output."

**STEP 7--List the criticality of each failure mode and the ensuing result on system performance or personnel safety**

The criticality analysis is done by establishing a ranking of the seriousness and implications of the failure. For example, a failure might be Critical, Major, Minor or Insignificant. The Critical failure is one which causes or can cause harm to personnel. It is a safety hazard. The Major fault is one which causes serious effect on operation and requires immediate attention. A Minor fault is one which does not cause immediate concern but will require attention in the near future. A failure which is Insignificant is one which can be tolerated because it has little or no effect on operation. One popular method of using this measure is as follows:

C - Critical: There is a safety hazard.

MA - Major: System performance is out of control; system is in need of immediate repair; service is required immediately.

MN - Minor: System performance is degraded but operation can continue; repair or correction is needed at earliest opportunity.

I - Insignificant: Failure has no immediate effect on system performance.

**STEP 8--List the measure of probability of the failure mode occurring**

Enter the measure of probability of the failure mode occurring. This entry may be very subjective and relate closely to the experience of the analyst, or it may be quantitatively calculated from actual test data or field use or from reference to an established part failure rate handbook. Another useful technique is to rank the relative probability of a part failure to the other possible failure modes in that system. For example, one method of establishing relative probability of failure is:

Relative degrees of probability  
of failure occurring.

H - High  
M - Moderate  
L - Low  
U - Unlikely

**STEP 9--Review the analysis, determine where corrective action is dictated and follow up to see that appropriate action is taken**

This is the most important step in the FMEA. The FMEA points the way to product improvement. The completed FMEA should be reviewed by the design review board to determine what follow up actions are required. Unless positive actions are taken to correct the deficiencies identified by the analysis, the task is only partially completed. The action items which are generated by the FMEA should be documented as shown by the Action/Responsibility column in Figure 4. Another very effective way to implement the follow up action is to use a separate "Action Items" sheet. The "Action Items" sheet should list each required action item as identified by the FMEA, the person responsible for the action, and a date for completing the action item. The design review board should review the findings and recommendations of the FMEA and the Action Items list with the design engineer or reliability engineer making the analysis and ensure that corrective action is taken.

# FAILURE MODE AND EFFECTS ANALYSIS

Identify who checked the completed FMEA. It is recommended that one person, for example, a design engineer, do the actual analysis, and another person perhaps a reliability engineer associated with the design, check the FMEA.

Identify who completed the FMEA.

Identify the product by drawing number and revision number/letter.

Identify the product, part subsystem, or equipment which is to be analyzed by the FMEA.

Enter the date when the FMEA was performed and the date when it was checked. The dates along with the revision number/letter provide good traceability, if needed, to the specific revision and when it was done.

As items are entered on the form, number them sequentially. This permits easy reference.

Enter the part number as it appears on the drawing, part list, etc.

Enter a brief description of the part as it appears on the drawing or part list used as reference.

Enter a brief description of the function(s) of the part being examined for possible failure modes.

Enter the failure mode which the part could possibly incur. Frequently there are 2 or more failure modes for a part, each of which could cause different effects on a system.

For each failure mode identified, enter the effect which that failure could have on the system performance.

Required follow up action.

This column is provided for clarifying or supplemental remarks as may be required.

FAILURE MODE & EFFECTS ANALYSIS										
PRODUCT		DRAWING #		REV.		DONE BY		CKD BY		
CODE:		CRITICALITY: (CRIT)		C - Safety Hazard MA - Major Fault - Requires Prompt Service MN - Minor Fault - May Require Future Service I - Insignificant		RELATIVE PROBABILITY OF OCCURRENCE: (PROB)		H - High M - Moderate L - Low U - Unlikely		
*This item suggested for further investigation or action.										
ITEM #	LINE/ PART NO.	DESCRIPTION	FUNCTION OF PART	MODE OF FAILURE	EFFECT ON SYSTEM	STEP 6..	STEP 7	STEP 8	STEP 9	ACTION/ RESPONSIBILITY
..STEP 3.	.....	.....	..STEP 4..	..STEP 5..	..STEP 6..	STEP 7	STEP 8	STEP 9		

Figure 4

To illustrate the procedure, first, an example of the FMEA is presented using a common appliance, the steam iron. Following the next section on the fault tree analysis, both of these methods are illustrated for a photovoltaic panel.

#### An Example of FMEA

In Figures 5 and 6, the steam iron example is shown. In the case of much larger systems or equipment, the larger system or equipment can, and often times, must be divided into smaller sub-systems for the purposes of analysis.

The first requirement is the descriptive information. Shown in Figure 5 is the Parts List. Additional information for an FMEA would be an electrical schematic and assembly drawings.

A portion of the Failure Mode and Effects Analysis for the steam iron is shown in Figure 6.

PARTS LIST			
ITEM: Steam Iron _____		Date: _____	
MODEL: HSSF44-A _____		Prepared: _____	
P/N	Part	Quantity	
1 8930	Plug . . . . .	1	
2 270931	Cord . . . . .	8 ft.	
3 9942	Handle . . . . .	1	
4 12877	Upper Cover . . . . .	1	
18 25303	Bimetal Strip . . . . .	1	
19 74903	Rivet . . . . .	1	
20 60872	Base Plate . . . . .	1	
21 63923	Pressure Plug . . . . .	2	

Figure 5

FAILURE MODE & EFFECT ANALYSIS									
PRODUCT: <u>Steam Iron</u>				DONE BY: _____					
DRAWING: <u>HSSF44 REV. A</u>				CKD BY: _____					
CODE:				RELATIVE PROBABILITY OF OCCURRENCE: (PROB)					
CRITICALITY: (CMT)				H - High M - Moderate L - Low U - Unclassified					
C - Safety Hazard MA - Major Fault - Requires Prompt Service MN - Minor Fault - May Require Future Service I - Insignificant									
ITEM	LINE/PART NO.	DESCRIPTION	FUNCTION OF PART	MODE OF FAILURE	EFFECT ON SYSTEM	CRIT	PROB	REMARKS	ACTION/RESPONSIBILITY
1	8930	Plug	2 Wire Electrical Plug	Short Open	No heat or steam No heat or steam	MA	L		
2	270931	Cord	Power from outlet to iron	Short Open Insulation Fail	No heat or steam No heat or steam Pressure shock hazard	MA	L	Lack info on insulation heat resistance	Check insulation specs vs. industry and Fed. Safety standards. R. Jones due next Design Review
3	9942	Handle	Hold iron, support in upright position.	Cracked, broken	Operator inconvenience to unusable	MN	L		
4	12877	Upper Cover	Mount handle, plate, cover insulator; bolt to lower plate.	Tarnished finish	None on operation.	MN	L		
18	25303	Bimetal Strip	Sense heat, open & close heat element circuit	Fail Open Fail Closed	No heat, no steam Iron too hot: Surface remains at max temp. of 350°F	MA	L		Prepare test plan for running life test on Bi-metal Strip. S. Harris Due next Design Review
19	74903	Rivet	Carries current for heating element	Loose, burned surface	Low Heat	MA	L		
20	60872	Base Plate	Hot ironing surface mount for components; grounds for steam	Tarnish Stripped Threads loose connection Clogged	None on operation None Decreased amount of steam	I	M		Determine cost of adding lock washer. L. Smith Due next Design Review
21	63923	Pressure Plug	Blow out due to overpressure	Not blow out at pressure limit	Burn hazard	C	L		a) Check field data for past history. R. Jones b) Draft test plan to check pressure plug. S. Harris c) CC establish sampling plan and inspection for plugs. N. Roberts All due next Design Review

Figure 6

ORIGINAL PAGE IS  
OF POOR QUALITY

## FTA

FTA Procedure

There are two significant differences between FTA and the FMEA. The first is the method of documentation. The FTA uses a set of standard logic symbols to represent events and relationships in the hardware. The FMEA, as shown, uses a part-by-part tabular form to identify failure modes. The second difference is the starting point of the analysis. The FTA begins at the top of the system with a statement of an undesired event in the system. The FMEA begins at the bottom, the component level, and works upward to the system level where the effect on the system performance is described.

The FTA begins with a statement of an undesired event. This establishes the top of the tree. Next, the events which can lead to the top event are identified. The events which can cause the next level are identified. A tree of events is thus established until the undesired events and failures are traced to the lowest identifiable level which most often leads to the component level.

A set of logic systems, Figure 7, is used to develop the fault tree. They are standard symbols which should be used when performing fault tree analysis.

*STEP 1--Collect the data to be used in the analysis*

Same as in Step 1 in FMEA procedure.

*STEP 2--Identify the Top Event (A Fault, Failure or Personnel Hazard)*

The top event is the starting point for the analysis and should therefore be well defined. It is an event, a malfunction, or failure which affects system performance or personnel safety. The top event should be definable and measurable.

In some cases there may be more than one top event in which case each fault tree can be developed individually. For example consider the steam iron again. The functions of a steam iron are:

- (1) to provide heat for ironing.
- (2) to provide steam when required.
- (3) and a necessary and inherent requirement to be reasonably safe for use.

Of course the "system" is going to be hot beyond human tolerance when it is being used and that is an acceptable feature but the possibility of electrical shock hazard must be considered. So, in defining the

top events there are three possible events which could be defined as top events:

- (1) temperature, absence of or too high
- (2) steam, none or present when not required
- (3) injury hazard, electrical shock.

Note that these three top events can be readily defined and measured.

#### STEP 3--*Develop the Fault Tree*

The development of a fault tree begins by stating the top undesired event such as a safety hazard, a system failure or some definable fault. (Use an event rectangle as indicated in Figure 7.) The starting point for the FTA is thereby established. The analysis continues by identifying the events on the next level down which could cause the top event. The analyst must study the events to determine if they will occur as an AND function or an OR function to cause the top event. (See Figure 8 examples.) The fault tree development continues in this manner downward from the top event and accounts for all of the contributing events which can lead to the top event. The development of the tree is concluded when the lowest possible level is reached to which a basic failure event can be assigned. The basic failure events are represented by a circle on the fault tree. The basic events are generally hardware failures, errors of commission, or errors of omission.

#### STEP 4--*Assign Quantified Values of Probability to Each Event on the Fault Tree*

The quantification of the basic fault events can come from several sources among which are: established source of component failure rates; failure rates from actual field use; estimates of rates of occurrences. For example, consider a gasoline driven motor-generator set. There are established failure rates for the electrical components which make up the voltage regulator "subsystem." These failure rates come from established sources of component failure rates. As for the motor, years of experience in using that type of motor may provide reliable failure rates. These failure rates come from actual field use. And an estimate may have to be made that one time in every x uses the operator will forget to check the gasoline tank and it will be empty. This is an estimated rate of occurrence based on the best information available. These are the kinds of data which are used to determine the probability of the top undesired event occurring.

#### STEP 5--*Review the analysis, determine where corrective action is dictated and follow-up to see that appropriate action is taken*

As in the FMEA, this is the most important step in the FTA. The completed FTA should be reviewed by the design review board to determine

what follow-up actions are required. Unless positive actions are taken to correct the deficiencies identified by the analysis, the task is only partially completed. The action items which are generated by the FTA should be documented on an "Action Items" sheet. The "Action Items" sheet is a very effective way to implement the follow-up action. It should list each required action as identified by the FTA, the person responsible for the action, and a date for completing the action. The design review board should review the findings and recommendations of the FTA and the Action Items list with the design engineer or reliability engineer making the analysis and ensure that corrective action is taken.

### Revisions

As design changes occur during the production life of the product, the FMEA and/or FTA should be revised to be kept current with the latest configuration. This becomes an important element in the entire documentation package.



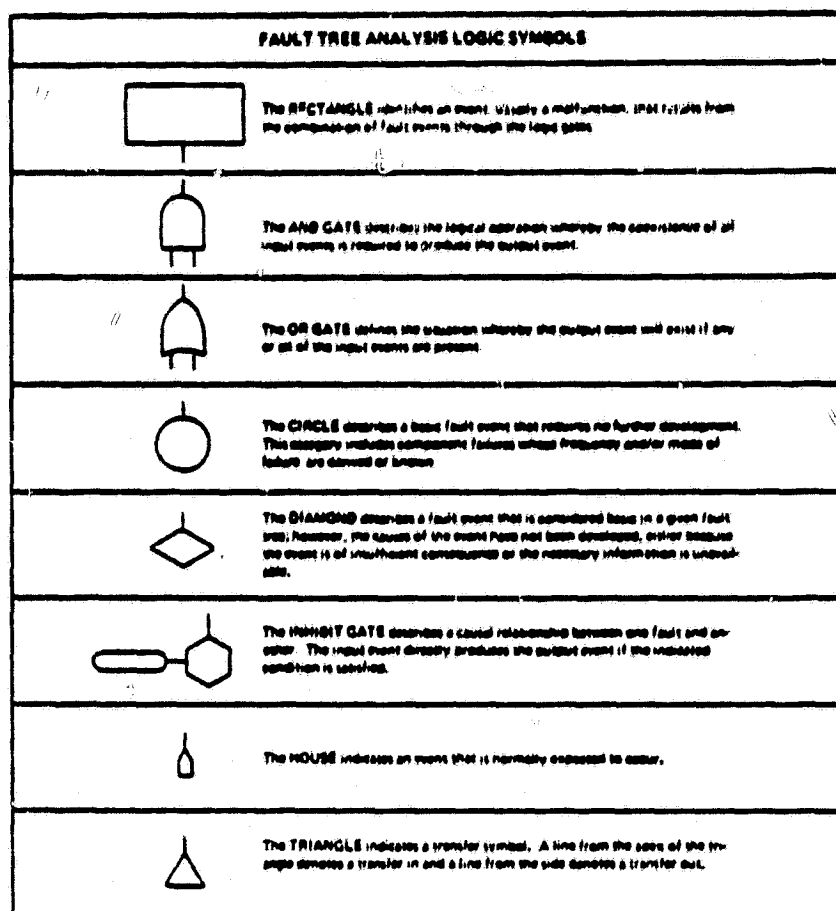


Figure 7

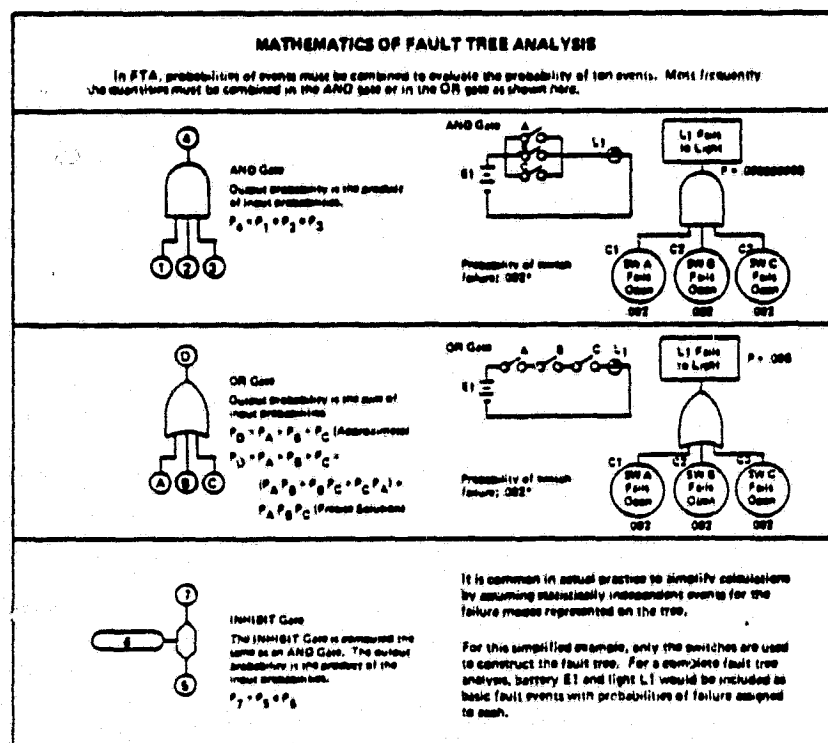


Figure 8

### An Example of FTA

The steam iron example used to illustrate the FMEA is used again here, this time applying the techniques of the FTA.

The steam iron performs two major functions: (1) provides heat, (2) provides steam. Suppose the undesired event was stated as "No Steam from Iron." This undesired event implies that there is no heat to make steam or no water to make steam.

The Fault Tree for "No Steam from Iron" would look like the tree shown in Figure 9.

Suppose a Fault Tree which looked just like the "No Steam from Iron" example was of a system for which event probabilities were available. The analysis could then be quantified as shown in Figure 10.

The event probabilities are:

C1	.005	C5	.001
C2	.0005	C6	.001
C3	.0005	C7	.80
C4	.002	E1	.06

This type of analysis permits a quantification of the top event or any of the lower contributing events. In the example of Figure 10 it can be seen that the top undesired event, R1, has a probability of occurrence of .058, or about 1 out of every 17 times. Further inspection shows that event R2 will occur 1 out of every 125 times and R3 will occur 1 out of every 20 times (occurrence probabilities of .008 vs. .050). It can be seen that events comprising R3 influence the undesired top event R1 more than R2 does. Further investigation shows that event R5 influences R3 more than does R4, and so on.

An analysis of this type is of value in identifying the areas where more effort such as design, test, or inspection would be of greatest value.

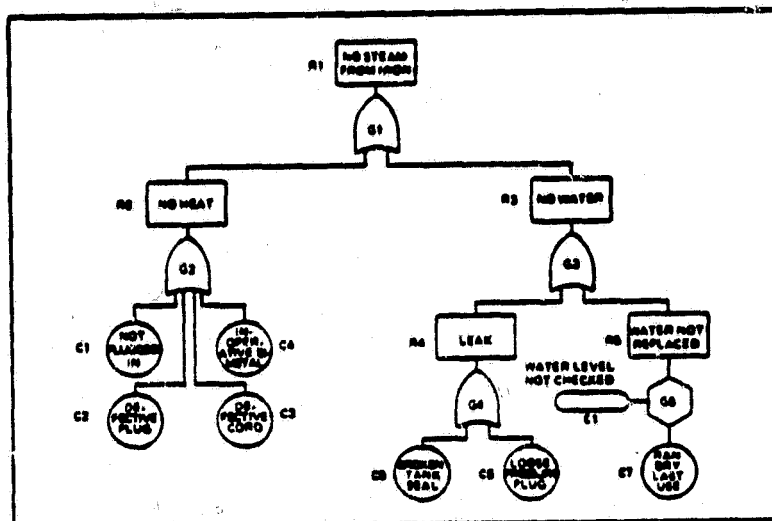


Figure 9

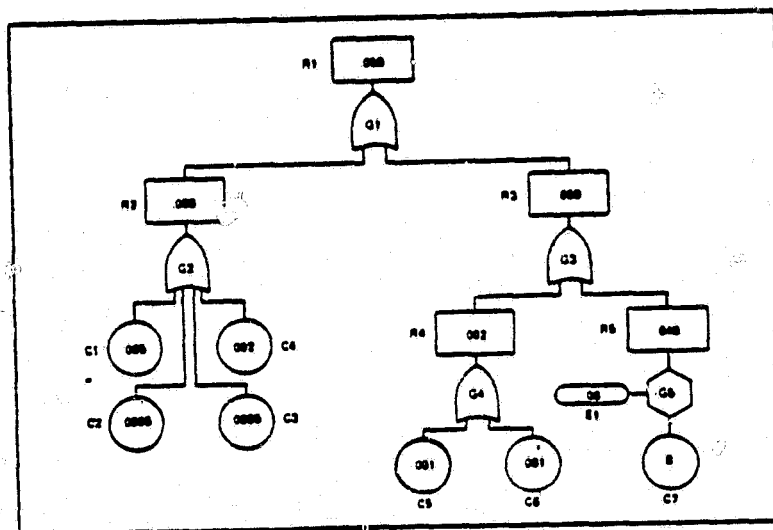


Figure 10

## An Example of FMEA/FTA Applied to a Photovoltaic Device

### A. FMEA

Using the guide given in the earlier discussion an FMEA was conducted for a Block III General Electric shingle. Several changes were made in the FMEA Analysis Form to conform to the special requirements of the device:

- 1) A column labeled Failure Cause(s) was added to make the document more useful by providing additional information.
- 2) Under Step 7--The "C" denoting Critical is replaced by one of the following:

CA = death  
CB = serious injury  
CC = minor injury

Data for Steps 1-4 were obtained from the General Electric Report, "Design, Fabrication, Test, Qualification and Price Analysis of 'Third-Generation' Design Solar Cell Modules."

The following page is the FMEA chart. The subjective conclusions concerning, for example, probability and criticality are illustrative of a best judgment result.

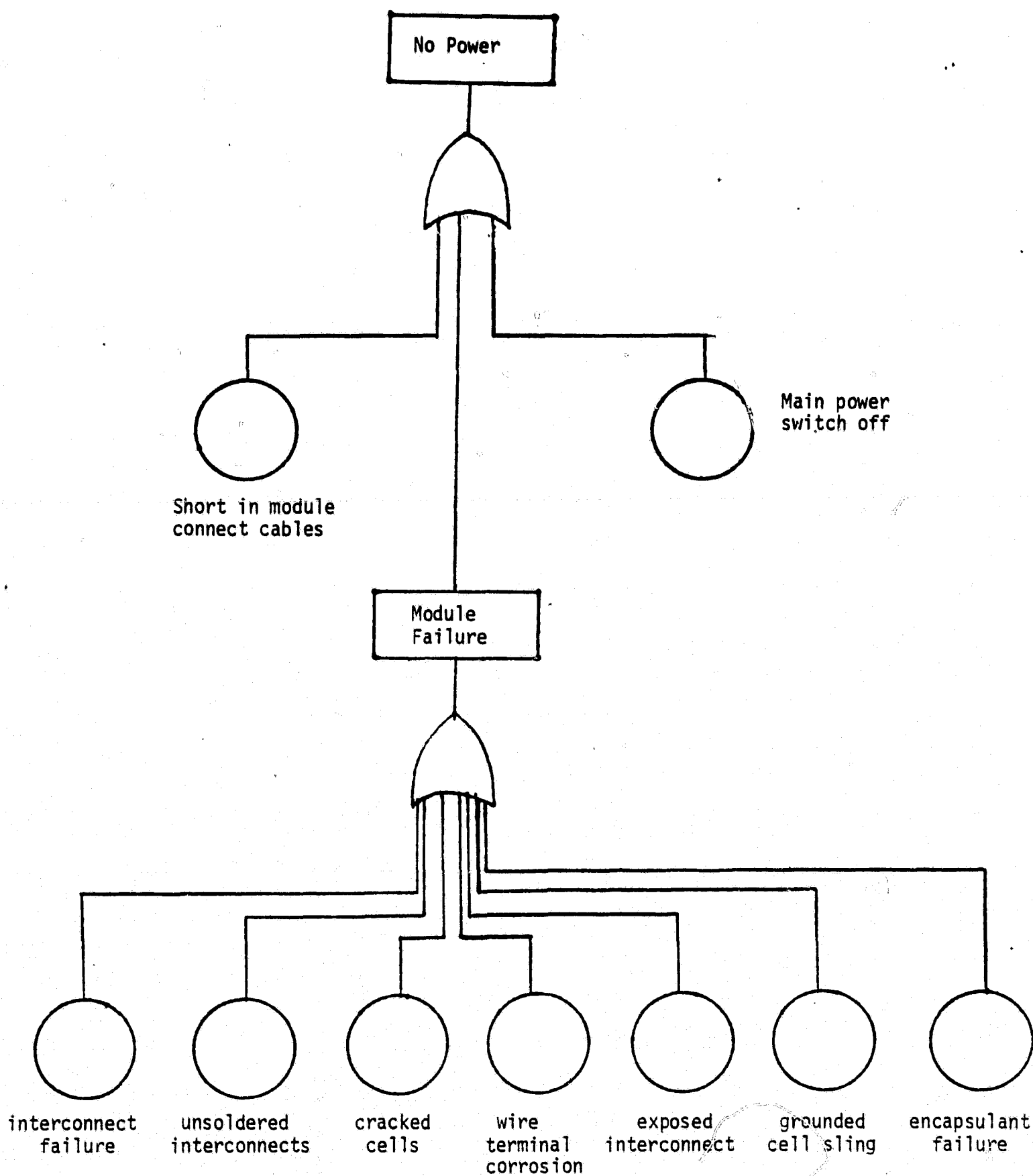
### B. FTA

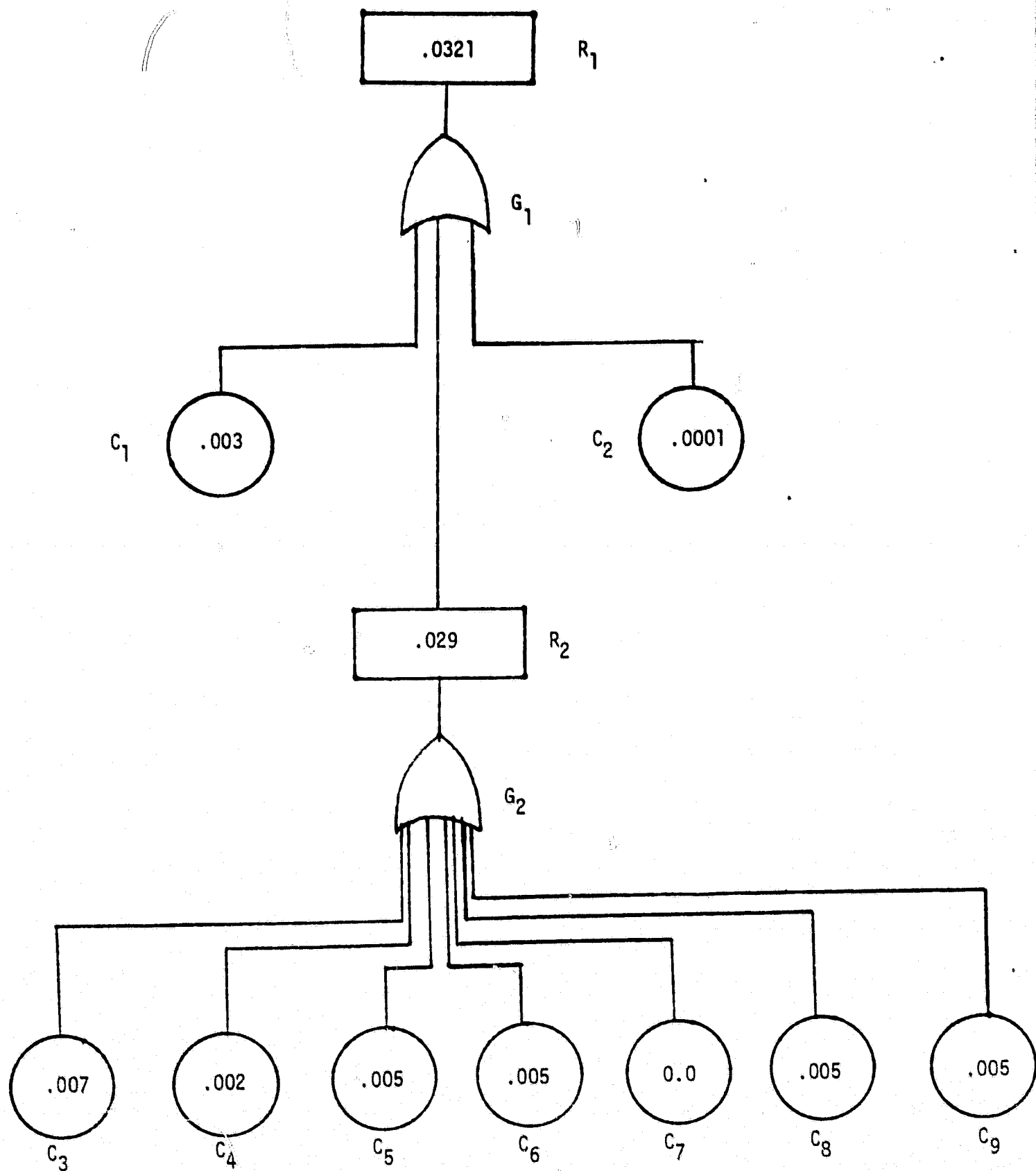
The data used in this FTA is the same as that used in the preceding FMEA. In this case the top event has been identified as "No Electrical Power." This is not to say that this is the only top event. The probabilities used in this FTA are only estimates and are included just to show the mathematics of Fault Tree Analysis. The example illustrates the use of the logic symbols and methodology described earlier.

ORIGINAL PAGE IS  
OF POOR QUALITY

# FAILURE MODE AND EFFECT ANALYSIS CRITICALITY ANALYSIS

Part, Assembly or Process: Block III Shingle Module										Prepared By: DGM	Date: 11/21/80
Item No.	Line/Part No.	Description	Function of Part	Mode of Failure	Failure Cause(s)	Criti- cality	Prob.	Effect on System	Corrective Action or Preventive Action	Remarks	
1	470254978	Cover plate (glass)	Protect cells	Glass breakage	1) hail 2) torsional load	MM MM	L M	Reduce system output	Replace cell		
2	47J254977	Solar cell	Produces electricity	1) Reverse bias 2) Breakage	Partial shadowing 1) hail 2) encapsulant outgassing	C/C MM MM	L L L	Reduces system voltage arcing. Possible fire from reverse bias	Replace cell	Check potential electrical shock hazard	
3	470252772	Substrate skin	Tear resistance weathering	1) Moisture transmission 2) Tears	Rain High winds	MM MM	U U	Reduces system voltage. Possible open circuit	Replace cell		
4	Silglaze SCS2402	Module en- capsulant	Prevent moisture from reaching cells and adhesion	1) Outgassing Loss adhesion	UV, wind, thermal moisture, poor workmanship	MM MM	M L	Reduce system output	Replace cell		
5	M6308 Super White Silaprene	Substrate adhesive	Bond various substrate layers together	Adhesive failure	1) high temperatures 2) torsional loading	MM MM	L L	Reduce system output	Replace cell		
6	47C252770	Rear cover	1) water proofing 2) fire resistance 3) sharp object penetration	Material failure	Excessive water Fire Roofing nails	MM MM MM	U M U	Reduce system output	Replace cell		
7	47B252771	Cell to cell interconnect	Electrical continuity	Interconnect failure	Thermal Poor workmanship	C/C C/C	M L	Arcing	Replace cell	Check potential electrical shock hazard	
8		Module to module interconnect	System-- electrical continuity	Wire breakage Corrosion Terminal breakage		MM MM MM	L L U	Arcing	Replace cell		





## SUMMARY

This report is an exploratory survey of the areas of concern, the generic types of hazards that can arise, the methodologies for analysis and the types of alternatives that can be devised to enhance safety and reduce liability in the use of photovoltaic energy sources. The report is not intended to be complete, but is to serve as a catalyst for generating the comprehensive procedures and analysis that should be part of the design formulation and manufacture of photovoltaic modules, arrays and systems.

It is safe to say that today's product liability climate will persist and can expose the module manufacturer to litigation over issues that seem remote from legitimate concerns over materials, production, performance and cost. Nevertheless, it is clear that the scenarios postulated in this report are foreseeable and will be thrust upon manufacturers as responsibilities for which they will be held accountable. It is simply insufficient for manufacturers to disclaim knowledge of errant human behavior, of foreseeable misuse or of well-meaning, but hazardous attempts to maintain or repair photovoltaic systems.

Of all the elements within the distributive chain from the manufacturer to the youngster playing on a partially-completed installation, it is the manufacturer who is generally held to have the knowledge of and should have accounted for the reasonably foreseeable events.

The appropriate time to interweave concerns for safety, reliability and performance is during the development phase of a new technology. This is the time for the photovoltaics industry to set up the procedures, implement the analyses and testing and generate the documentation.

If such an activity is begun now, the result will be safer and better understood products and a commensurate reduction in adverse liability.



## Appendix A

## WARNINGS

Warnings can be a means for reducing the risk of injury. However, a warning is not a substitute for good design. A warning should only be used if there is no other effective design alteration that could reasonably reduce the risk of injury.

The difficulties with warnings arises first from the fact that the language must be able to communicate with all persons who, potentially, can come in contact with the product and thus it is inevitable that certain classes of persons will not be benefited. Second, many if not most injuries result from inadvertent acts and warnings can have little effect on human behavior when attention is focused on a more important or distracting event. It is apparent, too, that the probability of a warning being read and remembered is generally quite low.

When a warning is to be used, however, it must be based upon the following considerations:

- a. A statement of the hazard or danger.
- b. A statement of the injury that can occur.
- c. A statement of the action to be taken to reduce or eliminate the risk.
- d. The language must be clear and easily understood by the majority of persons likely to come in contact with the product.
- e. Symbols, graphics, size and location must be such as to reasonably draw the attention of those to whom it is addressed.
- f. It must be sufficiently permanent to last for the useful life of the product to which it is attached.

For example, a warning that might be appropriate for each panel or module could read:

DANGER  
DO NOT TOUCH  
THIS IS AN ELECTRICAL DEVICE  
A SHOCK CAN KILL

Wires, boxes or anything else on the  
bottom may cause a shock. For proper  
handling, READ INSTRUCTIONS FIRST.

Depending on the foreseeable uses of a particular module design, the appropriate wording may be different and reference to instructions may be inapplicable or unnecessary. For an array, it may be appropriate to have the critical instructions permanently affixed to the structure for immediate access, since it is foreseeable that instructions are often misplaced or are inaccessible when needed.

Finally, specialized or technical language must be avoided. For example, such words and phrases as: "Modules," "connected in series," "terminals," "lethal" convey little meaning to the non-technical or unsophisticated person.

## Appendix B

The following data are extracted from the report "Larry Dumas Module Durability Experience," dated 9/23/80.

This is an example of the type of data and collection procedures necessary as a foundation for the safety analyses of the type suggested in this report. Such procedures and data should be standardized for effective use by all manufacturers.

Data is essential for FMEA/FTA studies, quality assurance programs, standards development and for cost/benefit analysis of proposed design modifications.



## LOW-COST SOLAR ARRAY PROJECT

[This is the type of data that should be collected in order to relate failures to environmental conditions.]

CATEGORY	LOCATION	LATITUDE (degrees)	ALTITUDE (feet)	KEY FEATURES
EXTREME WEATHER	CANAL ZONE (FT. CLAYTON)	9	-0	TYPICAL TROPIC: HOT AND HUMID; 100 INCH-PER-YEAR RAINFALL
MARINE	ALASKA (FT. GREELY)	64	1,270	SEMI-ARCTIC: DRY, COLD AND WINDY; -30°F WINTERS
	POINT VICENTE, CA	34	-0	COOL, DAMP MORNINGS AND CLEAR AFTERNOONS; CORROSIVE SALT SPRAY
	KEY WEST, FLA.	25	-0	HOT AND HUMID; CORROSIVE SALT SPRAY
	SAN NICHOLAS ISLAND, CA	34	-0	SOMEWHAT Milder THAN KEY WEST
MOUNTAIN	TABLE MOUNTAIN, CA	34	7,500	TYPICAL ALPINE ENVIRONMENT: HEAVY WINTER SNOWS AND MILD SUMMERS; HIGH-VELOCITY WINDS
HIGH DESERT	MINES PEAK, CO	40	13,000	CLEAR AND COLD; HIGH-VELOCITY WINDS, MAX. UV
	GOLDSTONE, CA	35	3,400	VERY HOT AND DRY SUMMERS; CLEAR SKIES
	ALBUQUERQUE, NM	35	5,200	DRY WITH CLEAR SKIES; AN ABUNDANCE OF UV
	DUGWAY, UTAH	40	4,300	COLD WINTERS, HOT SUMMERS; ALKALINE SOIL
MIDWEST	CRANE, INDIANA	39	-0	TYPICAL MIDWEST; HOT HUMID SUMMERS, COLD SNOWY WINTERS
NORTHWEST	SEATTLE (FT. LEWIS)	47	-0	TYPICAL NORTHWEST: MILD TEMPERATURES AND AN ABUNDANCE OF RAIN
UPPER GREAT LAKES	HOUGHTON, MICHIGAN	47	750	MILD SUMMERS, SEVERE WINTERS
URBAN SOUTHERN CALIFORNIA	JPL/PASADENA	34	1,250	PRIMARY TEST SITE - HOT SUMMERS AND MILD WINTERS; VERY HIGH POLLUTION ENVIRONMENT
URBAN COASTAL	NEW LONDON, CONNECTICUT	41	-0	TYPICAL NEW ENGLAND COASTAL
	NEW ORLEANS, LOUISIANA	30	-0	HOT AND VERY HUMID; HIGH POLLUTION ENVIRONMENT



## LOW-COST SOLAR ARRAY PROJECT

# SCOPE OF FIELD SURVEILLANCE

APPLICATIONS EXPERIMENTS	kW	ARRAY FAILURE	MODULE FAILURE	MOD. ELECT DEGR. (<25%)	PHYSICAL INSPECTION
• NASA LeRC SCHUCHULI INDIAN VILLAGE UPPER VOLTA VILLAGE (GSA BUY) REI:OTE STAND-ALONE	3.5 1.8 2.5	✓ ✓ ✓	✓ ✓		
• MIT LL NATURAL BRIDGES, UTAH MEAD, NEBRASKA BRYAN, OHIO RESIDENTIAL CHICAGO MUSEUM	100 28 15 22 2	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓		✓ ✓ ✓ ✓ ✓
• DOD MCOUNT LAGUNA, CALIFORNIA MILITARY APPLICATIONS	60 12	✓ ✓	✓	✓	✓
FIELD TEST SITES • NASA LeRC • MIT LL • JPL • SANDIA	33 9 9 4	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓

## LOW-COST SOLAR ARRAY PROJECT

## FIELD TEST &amp; APPLICATIONS

[This is for Illustration only. Data are to be considered as typical.]

BLOCK	INTERCONNECT FRACTURES	UNSOLDERED INTERCONNECTS	CRACKED CELLS	WIRE AND TERMINAL CORROSION	GROUND CELL STRING	EXPOSED INTERCONNECTS	ENCAPSULANT DELAMINATION
I	24	11	22	9	2	4	27
II	26	15	71	7	15	4	29
III	14	4	24	5	11	0	21
TOTAL	64	30	117	21	31	8	77

## Appendix C

Reprinted below is part of a report by S. E. Forman and E. E. Landsman, Safety Procedures for the 25-KW Solar Photovoltaic Array at Mead, Nebraska. It provides a written out step-by-step procedure for working on a photovoltaic array system. This is the type of communication that should be developed for all array systems.

### II. Electrical Work on Back Surface of Array

#### A. Preparation

1. Place those sections of the field to be worked on in the open-circuit mode via the field control panel in the trailer.

CAUTION: A high voltage exists within module strings. Avoid contact with modules.

2. Ground the array test box to the metal support frame being worked on by attaching the clip lead to the frame.
3. Verify that test box is set at open-circuit for all strings.
4. Pull all connectors from junction box of frame being worked on.

NOTE: There should be no arcing when disconnecting connectors. If arcs occur, notify supervisor before proceeding. Cap open junction box connectors.

5. Attach the connectors from each string on the frame to the test box via mating connectors that are in place on test box. Match string numbers when possible (i.e., unless they are not noted on connectors at the frame junction box).

6. Test all strings for leakage-current to ground.

NOTE: If meter dial registers more than 10 microamps, STOP, do not proceed with inspection.

Notify supervisor.

Return all ground switches to the OPEN position.

7. Measure and record in the log book the open-circuit voltage, short-circuit current, and ground currents for all strings being worked on. (Log book contains range of acceptable values.)

NOTE: Notify supervisor if discrepancies occur.

8. Place all strings in shorted condition in the test box.

- B. Connect a ground as close as electrically possible to each wire connected to the work site, but not at the work site.

OBJECTIVE: Guarantee that all wires are grounded even if disconnected during the work.

NOTE: A. Grounding connections may, under some conditions, draw an arc. Thus, keep eyes and skin away from the point of electrical contact.

B. When frame grounding, always attach lead to frame first, then to the point being grounded.

- C. Measure voltage directly from the work sites to the frame. Proceed with planned operation unless dangerous voltages are noted (over 50 volts).

- D. Upon completing planned operation, remove ground carefully as an arc may be drawn.

NOTE: Remove lead from grounded point first, then remove lead from frame ground.

- E. Open-circuit all strings.

- F. Remove string connectors from test box.

- G. Reconnect string connectors to proper points on frame junction box.

NOTE: There should be no arcing.



## BIBLIOGRAPHY

1. Safety Procedures for the 25-KW Solar Photovoltaic Array at Mead, Nebraska, S. E. Forman, E. E. Landsman, MIT Lincoln Labs, April 7, 1978.
2. Westinghouse document: A Guideline for the FMEA/FTA. MB-3350.
3. Products Liability and the Reasonably Safe Product: A Guide for Management, Design and Marketing, A. S. Weinstein, A. D. Twerski, H. R. Piehler and W. A. Donaher, John Wiley and Sons, New York, July 1978.
4. Interim Performance Criteria for Photovoltaic Energy Systems, SERI, Golden, Colorado, May 1980.
5. SAE ARP926A Fault/Failure Analysis Procedure, November 1979.
6. Operation and Maintenance Cost Data for Residential Photovoltaic Modules/Panels, Bent, Hall, Kosar, Rittlemann Associates, July 1980.
7. Final Report, Design, Fabrication, Test, Qualification, and Price Analysis of "Third-Generation" Design Solar Cell Modules, General Electric, March 1980.
8. Residential Photovoltaic Module Array Requirement Study, Bent, Hall, Kosar, Rittlemann Associates, June 1979.
9. Energy Storage for Photovoltaic Conversion Final Report--Utility Systems, Volume II, Westinghouse Corporation, September 30, 1977.